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This report is the second in a series describing manpower flow models for use in determining accession plans that provide sufficient input to the force, while preventing large surpluses and shortages in various force categories. The model described here expands a previous quarterly optimization model, the Recruit Input Optimization (RIO) Model, to allow specification of force goals in terms of structured strength and trained strength in addition to total strength. The optimization procedure minimizes a

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) weighted sum of the surpluses and shortages from force goals, subject to constraint equations that control the flow of personnel through the force. A future report will describe the development of an annual Optimal Accession Requirements (OAR) Model, whose smaller size allows it to be linked with other personnel planning models.

FOREWORD

This research and development was conducted under Exploratory Development Task Area ZF55-521-010 (Manpower Management Decision Technology), Work Unit 03.11. The work was conducted under the sponsorship of the Deputy Chief of Naval Operations (OP-01). The objective of the task area is to develop techniques to improve the Navy's managerial decision-making capabilities in the area of manpower and personnel. The work unit is concerned with the flow of recruits through the three non-rated pay grades into the petty officer grades.

This is the second in a series of reports relating to Work Unit 03.11. The first report (NPRDC TR 80-12) described the development of the Recruit Input Optimization (RIO) Model, a linear programming model for determining quarterly accession requirements to meet petty officer requirements over a 5-year planning horizon. This report describes the disaggregation of force requirements into structured billet, trained personnel, and untrained personnel requirements, and the development of an Accession Gaming Model (AGAM), an optimization model that incorporates these additional force goals.

Appreciation is expressed to CDR Russ Buckley of the Decision Support Systems Branch, Naval Military Personnel Command, who provided information on Navy structured billets and the requirements for trained personnel.

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SUMMARY

Problem

In the past, Navy enlisted manpower planning has focused on attaining a particular end strength and the accessions necessary to achieve that goal. Since end strengths are prematurely fixed in the programming, planning, and budgeting process, planned accessions serve only to meet fiscal year end strength. Consequently, the accession plan may not be able to satisfy other or more distant goals, such as future requirements for trained personnel, petty officers, and careerists.

Objective

To explore the accession planning problem in a more rigorous manner, a mathematical model--the Accession Gaming Model (AGAM)--was developed. The purpose of AGAM is to determine an all-Navy accession schedule that will satisfy certain force objectives over a 5-year period. Force objectives refer to petty officer, careerist, trained strength, and/or structured space requirements.

Approach

Linear goal programming was the principal mathematical technique employed in developing AGAM. For a given set of force goals, the linear programming procedure determines an accession policy that deviates as little as possible from the goals. User input is allowed in choosing goals and placing a relative "cost" or "penalty" on the failure to meet each goal. Thus, different perceptions of the importance of various goals will lead to different accession plans.

The Survival Tracking File for FY 1977 was used to obtain the quarterly flow rates used to simulate the flow of personnel through the force; and the Enlisted Master Record for the end of FY 1978, to obtain the distribution of trained, untrained, structured, and unstructured personnel by pay grade at a point in time. These data were used to simulate the movement of personnel over the 5-year period covered by each scenario.

Results

The IBM Mathematical Programming System, MPSX/370, was used to solve the linear programming model. Several test scenarios were set up, incorporating different force goals and priorities, and run for a 5-year planning period. The resultant changes in accession requirements give an indication of the sensitivity of the solution to changes in each of the various goals.

Future Developments

AGAM represents an intermediate step in the development of an accession planning model. It expands on a previous quarterly optimization model--the Recruit Input Optimization (RIO) Model--to allow specification of force goals in terms of structured strength and trained strength in addition to total strength. Since AGAM is too large to allow it to be linked to more comprehensive force management systems that can incorporate the effect of promotion, retention and attrition policies on accession planning, however, an annual Optimal Accession Requirement (OAR) planning model is being developed. OAR retains the comprehensiveness of AGAM but is small enough to allow it to be linked with other personnel planning models.

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Problem and Background

In the past, Navy enlisted manpower planning has focused on attaining a particular end strength and the accessions necessary to achieve that goal. Since end strengths are prematurely fixed in the programming, planning, and budgeting (PPB) process, planned accessions serve only to meet fiscal year end strength. Consequently, the accession plan may not be able to satisfy other or more distant goals, such as trained strength, future petty officer requirements, and careerist objectives.

Navy manpower can be classified into two major groupings: (1) those billets that are directly associated with accomplishing the service mission, sometimes called "structured spaces," and (2) those billets that are not involved with accomplishing the service mission as such, but are necessary to keep structured spaces filled, called "nonstructured spaces." This latter grouping includes training billets needed to replace personnel losses from structured spaces, as well as billets to accommodate transients, patients, and prisoners (TPP). Total manpower requirements are simply the sum of structured and nonstructured spaces.

If end strength is allowed to completely determine accessions (remembering that end strength is fixed fairly early in the POM process), then additional nonstructured space requirements to support the approved structure can be acquired only at the expense of structured spaces. In the current process, it is both fortuitous and accidental if the total number of billets is sufficient to support both structured and nonstructured needs. Thus, "the allocation choice comes down to a short-term undermanning of structure to fully support nonstructured needs so that long-term structure needs will be met, or a short-term support of the structure by undermanning of nonstructured spaces that ensures that long-term needs of the structure will not be met.[1]

Recognizing this situation, the Department of Defense has expressed an interest in shifting away from meeting an end strength (or man-year average) and toward meeting a "trained strength" requirement. The classification of the Navy's enlisted force into trained, untrained, structured, and nonstructured categories is shown in Figure 1. As shown, the unstructured categories consist of TPP in support of both trained and untrained personnel, trained personnel receiving additional training (students), and untrained personnel receiving initial training (trainees). A trained individual is defined as one who either has 2 or more years of service or has arrived at his first duty station (assigned to a structured billet), excluding Naval Training Centers (NTCs) and "A" schools. The question now becomes how many accessions are required to ensure an adequate level of trained strength or "structured spaces" so that the Navy can fulfill its missions, not how many accessions are required to satisfy an end strength or man-year average.

Objective

To explore the accession planning problem in a more rigorous manner, the Accession Gaming Model (AGAM) was developed. The purpose of AGAM is to determine an all-Navy accession schedule that will satisfy certain force objectives over a 5-year period. Force objectives refer to the number of petty officers, careerists, trained strength, and/or structured space requirements.

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[1]Rea, Edward. Memorandum from the Office of Management and Budget, Subj: Navy Enlisted Manpower Planning: A Critique," 10 September 1974.

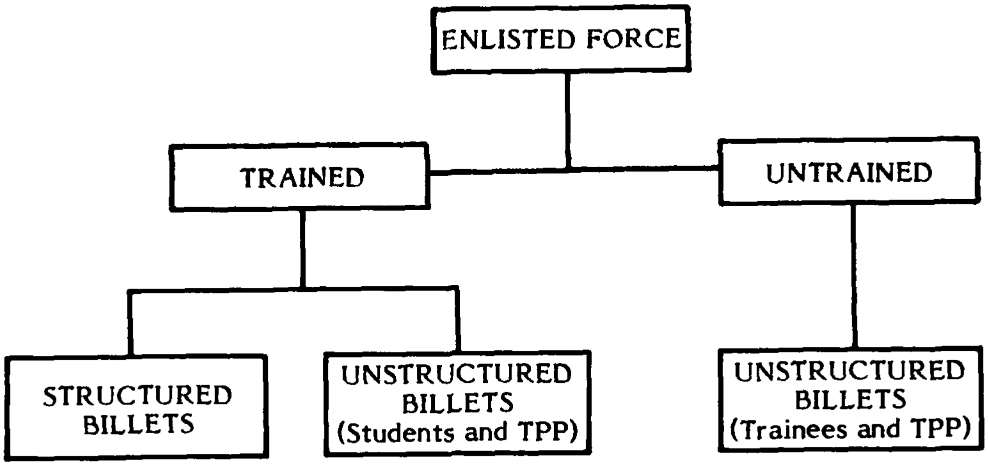

Figure 1. Classification of the Navy's enlisted force into trained, untrained, structured, and unstructured categories.

APPROACH

The AGAM model uses a linear goal programming approach (see Mathematical Formulation). It requires as input the initial personnel inventory and goals representing the 5-year petty officer, careerist, and trained strength requirements. AGAM is designed so that the user can "influence" the model to satisfy one or more objectives in 1 or more of the 5 planning years. For example, the user can determine an accession plan that satisfies the petty officer requirements for the third and fourth planning years or the trained strength requirements in the second and fifth years. The output from AGAM includes the optimal accession schedule for each quarter in the planning period, as well as the total number of trained personnel (structured billets, TPP, and students) and untrained personnel (TPP and trainees). Deviations from all the objectives are given so the user can readily see where shortages and surpluses occur.

Data Requirements

Quarterly personnel flow rates, which describe how enlisted personnel enter, move up (or down) the grade structure, and leave the force from one quarterly time period to the next, are of crucial importance to AGAM. These flow rates were obtained from the Survival Tracking File (STF),[2] a data source containing extracts of Enlisted Master Records (EMRs) arranged in chronological order by individual. The STF "tracks" each enlisted member such that any time a significant change occurs in the person's status, an updated EMR extract record is reflected in the file. This allows the type of change and

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[2]Gay, K. and Borack, J. I. Survival Tracking File (STF) (NPRDC Tech. Rep.), San Diego: Navy Personnel Research and Development Center, in preparation.

the date of the change to be inferred. Since significant changes in status include changes in pay grade, as well as accession and loss, all of the necessary flow rates can be derived. The rates currently used by AGAM were determined from the four quarters of FY77. Although using four sets of quarterly rates for each planning year would allow seasonal flow effects to be included in the model, these rates also reflect FY77's accession loading, basic and entry-level training, and promotion schedule. Hence, the four sets of quarterly rates were averaged to yield one set of quarterly flow rates so that AGAM can provide a future optimal accession plan that is independent of previous accession and promotion schedules.

Another requirement for data pertains to the relationships among the categories in Figure 1. Since only the structured billets are given, all other billet categories must be determined through a set of ratio coefficients. As shown in Table 1, these coefficients include Trained TPP/Structured, Students/Structured, Trained/Total Force, and Untrained TPP/Trainees. All ratios are on a pay grade basis except for Trained/Total Force, which is based on the first 8 quarterly time-in-service (TIS) cells. We can therefore determine such information as the number of TPP E-2s required to support structured E-2s, the number of student E-4s required to support structured E-4s, and the proportion of individuals in quarterly TIS cell 4 (i.e., 3-4 quarters of service) considered trained (or untrained). All the coefficients were computed by processing the EMR file for 30 September 1978, the end of FY78. Data elements such as current and past duty station, pay grade, TIS, and the activity accounting code were examined to categorize each enlisted member into two of the categories in Figure 1 (one of Trained/Untrained and one of Structured/Unstructured). Simple division by pay grade totals or TIS totals yielded the desired ratios presented in Table 1.

Table 1

Force Ratio Coefficients for AGAM

	Pay Grade				
Billet Categories	E-1	E-2	E-3	E-4	E-5
Trained TPP/Structured	.2845	.0740	.0464	.0506	.0466
Students/Structured	.0073	.0158	.0098	.0212	.0134
Trained/Total Force	.2821	.8729	.8625	.9163	.9984
Untrained TPP/Untrained Student	.1712	.3637	.1734	.1249	.1381

Mathematical Formulation

As noted previously, AGAM represents an application of goal programming techniques. Goal programming is an adaptation of the familiar technique of linear programming. In linear programming, the planning problem is represented by a number of constraints and an objective function to be optimized (cost minimization/profit maximization). The levels of the various activities to be rescheduled are represented as variables whose values are to be determined in accordance with the optimization criterion and the conditions imposed by the constraints.

In the case of goal programming, a number of goals are admitted that need not be mutually compatible. Each goal is represented as if it were an equality constraint, with the addition of two goal variables that represent any under- or overachievement of the goal target.

Constraints can be included in a goal program. Thus, the goal program formulation consists of a number of constraints representing conditions that must be met, and a number of goals or targets that represent the various manpower/personnel goals for the system. Additionally, there is an objective function, which is composed of the sum of deviations between the goals and the obtained values multiplied by a cost or penalty factor for each deviation.

The objective of accession gaming is to schedule the number of accessions (recruits plus prior-service gains) during each quarterly time period, so as to achieve three major goals: (1) satisfy trained strength by pay grade, (2) satisfy the requirement for petty officers, and (3) satisfy the need for careerists (defined to be the proportion of the enlisted force with TIS greater than or equal to 4 years).

Since new recruits, for the most part, go through some schooling at a training facility, highly oscillatory recruitment policies would incur large costs in the repeated opening and closing of facilities and reassignment of staff. Hence, the recruitment levels should be constrained to avoid large fluctuations from one time period to another. This leads to two additional goals: (1) reduce oscillations in the recruitment schedule (to reduce training costs); and (2) limit entry level training input to avoid exceeding "A" school capacity.

Constraint Equations--Flow Equations

The following notation is used throughout this report:

T = Planning horizon in quarters.

T_{FY} = Planning horizon in fiscal years.

K = Maximum time-in-service (TIS).

G = Number of pay grades.

t = Index for time period, $t = 1,2,\ldots,T,T+1$.

FY = Index for the end fiscal year.

i,j = Index for pay grades, $i = 1,2,\ldots,G$, $j = 1,2,\ldots,G$

k = Index for TIS, $k = 0,1,2,\ldots,K$.

$k=0$ is the accession with no prior service experience.

$k=K$ is the sum of all time in service greater than or equal to K.

Time period t = Time interval between observation point t and t+1.

$S_{ik}(t)$ = Inventory in pay grade i, at the beginning of time period t, with TIS index k.

$f_{ijk}(t)$ = Number of individuals moving from grade i, during time period t, to pay grade j, with TIS k at the beginning of period t.

f_{ijk} consists of only those individuals remaining until the end of the time period; that is, the net flow of personnel. For $j < i$, $f_{jik}(t)$ denotes the promotions from pay grade j, during time period t, into pay grade i, with TIS index k. For $\ell > i$, $f_{\ell ik}(t)$ denotes demotions from pay grade ℓ, during time period t, to pay grade i with TIS index k. $f_{iik}(t)$ denotes the continuation flow of personnel in pay grade i, during time period t, remaining in pay grade i, with TIS index k. $f_{0ik}(t)$ denotes the accessions entering the system in pay grade i, during time period t, with k time periods of prior service experience. When k=0, f_{0i0} denotes the recruits (i.e., those with no prior service experience). Thus, total accessions, A(t), includes both prior service gains and recruits.

At a given point of time, say t+1, inventory and flow are directly related by the conservation of flow equations described below.

The inventory of pay grade i with TIS k+1 at t+1, $S_{i,k+1}(t+1)$, is the sum of accessions (prior service gains) to pay grade i with prior service index k, $f_{0ik}(t)$, promotions from grade j ($j < i$) with TIS index k to pay grade i, $f_{jik}(t)$, continuations from pay grade i with TIS index k, $f_{iik}(t)$, and demotions from pay grade ℓ ($\ell > i$) with TIS index k to pay grade i, $f_{\ell ik}(t)$, during the time period t:

$$S_{i,k+1}(t+1) = f_{0,i,k}(t) + \sum_{j=1}^{i-1} f_{jik}(t) + f_{iik}(t) + \sum_{\ell=i+1}^{G} f_{ik}(t) \tag{1}$$

i,j,ℓ = 1,2,. . .,G (pay grades)
k = 1,2,. . .,K-2 (TIS)
t = 1,2,. . .,T (planning periods)

Boundary Conditions:

1. Recruits entering the enlisted system at pay grade i, during time period t, will be in pay grade i with TIS index 1 at time t+1.

$$S_{i,1}(t+1) = f_{0,i,0}(t)$$

i = 1,2,. . .,G (pay grades)

$S_{ik}(1)$ is the given beginning inventory

i = 1,2,. . .,G (pay grades)
k = 1,2,. . .,K (TIS)

2. The inventory of pay grade i with TIS K at time (t+1), $S_{i,K}(t+1)$, is the sum of two groups of individuals. The first group consists of the flows of those individuals who have TIS index K-1 at time t; and the second group, of the flows of those individuals who have TIS index K at time t. (TIS index K includes all TIS greater than and equal to K.) The flow equation states:

$$S_{iK}(t+1) = f_{0iK-1}(t) + \sum_{j=1}^{i-1} f_{jiK-1}(t) + \sum_{\ell=i+1}^{G} f_{\ell iK-1}(t) + f_{iiK-1}(t)$$

$$+ f_{0iK}(t) + \sum_{j=1}^{i-1} f_{jiK}(t) + \sum_{\ell=i+1}^{G} f_{\ell iK}(t) + f_{iiK}(t)$$

$$i,j,\ell = i,2,\ldots,G \text{ (pay grades)}$$
$$t = 2,\ldots,T \text{ (planning periods)}$$

See Figure 2 for a graphic representation of a flow pattern.

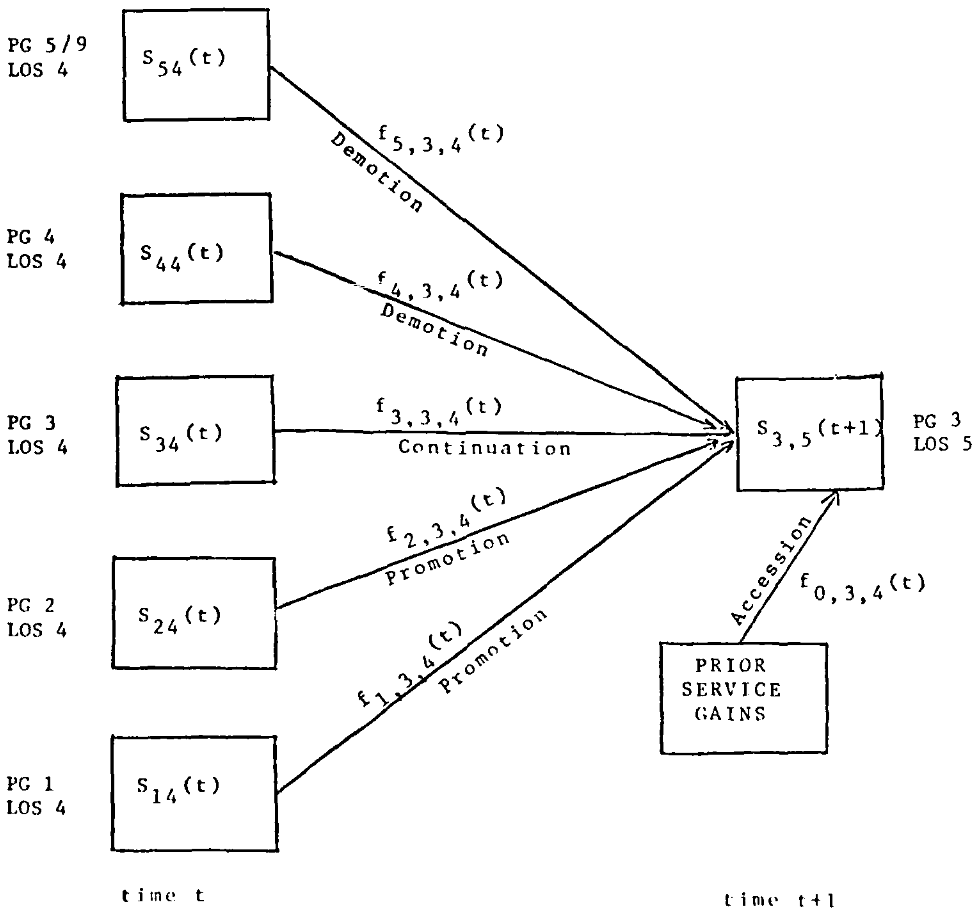

Figure 2. Representation of a flow pattern.

The above formulation of the problem has very little structure and, hence, too many variables. To reduce the number of variables, it was assumed that the fraction of the inventory in pay grade i with TIS k at time t that flows to pay grade j *during time period* t, is a fixed number, independent of planning period t and independent of the inventory at time t, $S_{ik}(t)$. This is a cross-sectional flow model. Thus,

1. P_{jik} is the promotion fraction of the inventory in pay grade j, with TIS k, that flows into pay grade i.

$$f_{jik}(t) = P_{jik}S_{jk}(t)$$

i = 2,3,. . .,G (pay grade)
(no promotion into grade 1)

j = 1,2,. . .,i-1 (pay grades)

k = 1,2,. . .,K (TIS)

t = 1,2,. . .,T (planning periods)

2. C_{iik} is the continuation fraction of the inventory in pay grade i with TIS k.

$$f_{iik}(t) = C_{iik}S_{ik}(t).$$

i = 1,2,. . .,G (pay grades)

k = 1,2,. . .,K (TIS)

t = 1,2,. . .,T (planning periods)

3. $D_{\ell ik}$ is the demotion fraction of the inventory in pay grade ℓ, with TIS k, into pay grade i.

$$f_{\ell ik}(t) = D_{\ell ik}S_{\ell k}(t).$$

i = 1,2,. . .,G-1 (pay grades)
(no demotions into pay grade G)

ℓ = i+1, i+2,. . .,G (pay grades)

k = 1,2,. . .,K (TIS)

t = 1,2,. . .,T (planning periods)

4. Accessions during time period t, A(t), are divided into prior service gains and recruits. Let G_{ik} be the fraction of accessions considered as prior service gains to pay grade i with TIS k. In particular, G_{i0} is the fraction of recruits with pay grade i.

$$f_{0ik}(t) = G_{ik}A(t)$$

$$f_{0i0}(t) = G_{i0}A(t)$$

$i = 1,2,3,\ldots,G$ (pay grades)

$k = 1,2,\ldots,K$ (TIS)

$t = 1,2,\ldots,T$ (planning periods)

Using promotion, demotion, continuation, prior service gains, and recruitment fractions, the conservation of flow equations can be restated as:

$$S_{i,k+1}(t+1) = G_{ik}A(t) + \sum_{j=1}^{i-1} P_{jik}S_{jk}(t) + \sum_{\ell=i+1}^{G} D_{\ell ik}S_{\ell k}(t) + C_{iik}S_{ik}(t)$$

$i,j,\ell = 1,2,\ldots,G$ (pay grades)

$t = 1,2,\ldots,T$ (planning periods)

$k = 1,2,\ldots,K-2$ (TIS)

$$S_{i,1}(t+1) = G_{i0}A(t)$$

$i = 1,2,\ldots,G$ (pay grades)

$t = 1,2,\ldots,T$ (time periods)

Boundary Conditions:

$$\begin{aligned} S_{iK}(t+1) = {} & G_{i,K-1}A(t) + \sum_{j=1}^{i-1} P_{j,i,K-1}S_{j,K-1}(t) \\ & + \sum_{\ell=i+1}^{G} D_{\ell,i,K-1}S_{\ell,K-1}(t) + C_{i,i,K-1}S_{i,K-1}(t) \\ & + G_{iK}A(t) + \sum_{j=1}^{i-1} P_{jiK}S_{jK}(t) + \sum_{\ell=i+1}^{G} D_{\ell iK}S_{\ell K}(t) \\ & + C_{iiK}S_{iK}(t). \end{aligned}$$

$S_{ik}(1) \quad = \quad Inv_{ik}$ (i.e., given beginning inventory).

Constraint Equations--Goal Constraints

1. Satisfy the trained strength requirement by pay grade over the entire (quarterly) planning horizon. For each pay grade i, there is a fixed fraction r_i of that pay grade inventory who have been assigned to a permanent duty station. We also assume an individual is trained if his TIS is greater than or equal to 2 years (see Table 1).

$$\text{Trained Strength}_i(t) = r_i \sum_{j=1}^{K} S_{ij}(t) + G_1^-(t) - G_1^+(t)$$

$$i = 1,2,\ldots,G \text{ (pay grades)}$$

$$t = 2,3,\ldots,T+1 \text{ (planning periods)}$$

$G_1^-(t)$ and $G_1^+(t)$ are, respectively, underachievement and overachievement of the goal at time period t.

2. Satisfy petty officer requirements over all the (yearly) planning periods. The petty officer force represents the professional enlisted structure necessary to perform and supervise the large number and variety of tasks constituting the Navy's missions. There is a need to satisfy the petty officer end strength as closely as possible at the end of each fiscal year.

$$\text{E-4/9 end strength (FY)} = \sum_{j=1}^{K} \sum_{i=4}^{G} S_{ij}(FY) + G_2^-(FY) - G_2^+(FY)$$

$$\text{E-5/9 end strength (FY)} = \sum_{i=5}^{G} \sum_{j=1}^{K} S_{ij}(FY) + G_3^-(FY) - G_3^+(FY)$$

$$FY = 1,2,\ldots,T_{FY} \text{(planning periods)}$$

$G_2^-(FY)$, $G_3^-(FY)$ represent underachievement; and $G_2^+(FY)$, $G_3^+(FY)$, overachievement for those goals for fiscal year FY.

3. Satisfy career force requirements over the (yearly) planning horizon. The career force consists of those individuals with at least 4 years (16 quarters) of active service.

$$\text{Career Force (t)} = \sum_{j=17}^{K} \sum_{i=1}^{G} S_{ij}(FY) + G_4^-(FY) - G_4^+(FY)$$

$$FY = 1,2,\ldots,T_{FY}$$

$G_4^-(t)$ and $G_4^+(t)$ are, respectively, underachievement and overachievement of the goal at each time period.

4. Reduce oscillations in recruitment between adjacent (quarterly) time periods. This will reduce basic training costs, help to equalize promotion opportunity, and help to assure an adequate number of qualified promotion resources at each time period. This can be accomplished by limiting the percentage oscillation in recruitment during adjacent (quarterly) time periods.

$$\sum_{i=1}^{G} S_{i,1}(t+1) - h(t) \sum_{i=1}^{G} S_{i,1}(t) - G_5^+(t) \leq 0$$

$$\sum_{i=1}^{G} S_{i,1}(t+1) - g(t) \sum_{i=1}^{G} S_{i,1}(t) + G_5^-(t) \geq 0$$

$$t \quad = 2,3,\ldots,T+1 \text{ (planning periods)}$$

$h(t)$ and $g(t)$ are user-selected constants that are proportions of change between time periods. $G_5^-(t)$ and $G_5^+(t)$, respectively, are underachievement and overachievement of the goal at each time period.

5. Satisfy upper and lower bounds on "A" school training capacity over (yearly) time periods so that a certain percentage of recruits will be assigned to "A" school training and the remaining recruits will be assigned to on-the-job training (OJT).

$$\sum_{t \in FY} b(t) \sum_{i=1}^{G} S_{i1}(t) - G_6^-(FY) \geq \text{"A" school capacity lower limit (FY)}$$

$$\sum_{t \in FY} b(t) \sum_{i=1}^{G} S_{i1}(t) - G_6^+(FY) \leq \text{"A" school capacity upper limit (FY)}$$

$$t \quad = 1.2,\ldots,T_{FY} \text{ (planning periods)}$$

$b(t)$ is the percentage of recruits assigned to an "A" school training program. $G_6^-(FY)$ and $G_6^+(FY)$ are underachievement and overachievement from the goal, respectively.

Objective Function

If we assign a per-unit weight (penalty) of $C_i^+(t)$ to each corresponding overachievement goal variable $G_i^+(t)$, and weight $C_i^-(t)$ to each corresponding underachievement goal variable $G_i^-(t)$, the objective function is merely the summation of all weights applied to all the corresponding goal deviation variables. That is, the objective of this model is to minimize Z, where

$$Z = \sum_{t=2}^{T+1} C_1^+(t)\ G_1^+(t) + \sum_{t=2}^{T+1} C_1^-(t)G_1^-(t) + \sum_{FY=1}^{T_{FY}} C_2^+(FY)G_2^+(FY)$$

$$+ \sum_{FY=1}^{T_{FY}} C_2^-(FY)G_2^-(FY) + \sum_{FY=1}^{T_{FY}} C_3^+(FY)G_3^+(FY) + \sum_{TY=1}^{T_F} C_3^-(FY)G_3^-(FY)$$

$$+ \sum_{FY=1}^{T_{FY}} C_4^+(FY)G_4^+(FY) + \sum_{FY=1}^{T_{FY}} C_4^-(FY)G_4^-(FY) + \sum_{t=2}^{T+1} C_5^+(t)G_5^+(t)$$

$$+ \sum_{t=2}^{T+1} C_5^-(t)G_5^-(t) + \sum_{FY=1}^{T_{FY}} C_6^+(FY)G_6^+(FY) + \sum_{FY=1}^{T_{FY}} C_6^-(FY)G_6^-(FY)$$

With the objective function formulated as just described, the program simply minimizes the total discrepancy between goal achievements and goal targets over all time periods. By using different penalty weights, one can place higher priority on attaining certain goals at the expense of other less important ones. Thus, we can determine the best accession policies when different levels of importance are attached to the goals.

MODEL EVALUATION

For AGAM, the Enlisted Personnel System is divided into five pay grades and 41 TIS intervals. The first four pay grades represent E-1, E-2, E-3, and E-4, and the fifth pay grade aggregates pay grades E-5 through E-9. The first 40 TIS intervals represent TIS of 0-1 through 39-40 quarters of service (as measured by Active Duty Service Date), while the 41st TIS interval represents all individuals with TIS greater than 40 quarters.

AGAM uses a goal program to determine the quarterly accession plan for a 5-year planning horizon and is driven by quarterly flow rates and user-supplied trained strength goals, petty officer goals, and careerist goals. Additionally, AGAM is restricted by the quarterly oscillation limits and "A" school capacity.

Four sets of quarterly flow rates have been obtained from the STF using FY77 data, and one uniform set of quarterly flow rates have been estimated from these data (see appendix). For purposes of testing, the "A" school percentage has been set to 75 percent and the quarterly oscillation limits have been restricted to ± 15 percent from the previous quarter.

The IBM linear programming software package, MPSX/370, has been used to operationalize the model. Several numerical examples have been attempted to study the behavior of the model when the priority order of the goals varies. A standard set of constant end strength goals were used for trained, petty officer, and careerist strengths through all time periods (see Table 2).

Table 2

Constant End Strength Goals

Goal	End Strength
Trained Strength PG:	
E-1	10,406
E-2	46,264
E-3	77,109
E-4	83,596
E-5/9	190,210
Career Force Requirements	196,180
Petty Officer Requirements:	
E-5/9	190,820
E-4/9	281,400
Upper Bound on "A" school Capacity	72,000
Lower Bound on "A" school Capacity	56,000

For the initial baseline run, all penalty values for failing to meet end strength or oscillation goals were set equal to one. This resulted in both a reasonable accession policy and force configuration for the 5-year planning horizon, and was therefore used as a baseline from which changes were made in the penalty values for a number of test scenarios. These scenarios were chosen to concentrate heavy priority on one particular goal at a time (with others being given the baseline weight of one). The scenarios are as follows:

1. Meet petty officer strength at end of year 1. This, of course, is not possible without bringing in huge numbers of accessions in order to get the required number of prior-service petty officer gains or direct petty officer accessions needed in such a short period of time. By weighting the penalty for failing to meet petty officer strengths 1 year out at 50 times its baseline level, however, we can determine the necessary change in accession policy due to an attempt to quickly increase the petty officer force.

2. Meet petty officer strength at end of year 3. Again, a weight of 50 is applied to the petty officer strength goal, but this time the horizon is long enough to allow recruit accessions to flow into the petty officer grades by normal promotion policies.

3. Meet careerist strength at end of year 4. This scenario is similar in purpose to scenarios 1 and 2.

4. Meet trained strength at end of year 1. This scenario attempts to meet the five pay grade trained strength goals as nearly as possible within 1 year. As most accessions will be to the lower pay grades, these goals will be more easily attained than the trained strength goals for petty officers.

5. Meet trained strength in all years. This scenario is one that could be used by a Navy planner who is primarily interested in meeting trained strength requirements, and who considers all years equally important.

6. Meet total end strength on a year-by-year basis. This scenario operates 1 year at a time, bringing in exactly enough accessions to counter the number of losses in each year. At the end of 5 years of this policy scenario, we can analyze how well the force meets petty officer and careerist goals.

7. The baseline case (all penalties equal to one).

Tables 3 and 4 depict some of the results derived from the scenario runs. Table 3 shows the effect on a particular goal (trained E-3 strength and E-4/9 end strength, respectively) across time periods, while Table 4 looks at the end of year 4 of each scenario and shows how well each of the various goals are met.

Table 3

Effect of Scenario Runs on Certain Goals

Scenario		Year 1	Year 2	Year 3	Year 4
Trained E-3 Strength at End of Years 1-4 (Desired Strength = 77,109 Each Year)					
1.	Result	74,313	77,793	72,562	76,981
	Goal Deviation	-2,796	684	-4,547	-128
2.	Result	73,569	74,522	76,668	73,491
	Goal Deviation	-3,540	-2,587	-441	-3,618
3.	Result	73,395	72,666	73,860	71,346
	Goal Deviation	-3,714	-4,443	-3,249	-5,763
4.	Result	72,571	71,969	76,437	74,995
	Goal Deviation	-4,538	-5,140	-672	-2,114
5.	Result	76,226	77,109	77,109	77,109
	Goal Deviation	-883	0	0	0
6.	Result	72,278	71,639	70,518	70,380
	Goal Deviation	-4,831	-5,470	-6,591	-6,729
7.	(Baseline)				
	Result	73,588	74,205	76,598	74,823
	Goal Deviation	-3,521	-2,904	-511	-2,286
E-4 to E-9 End Strength in Years 1-4 (Desired Strength = 281,400 in all Years)					
1.	Result	278,126	280,232	286,383	286,358
	Goal Deviation	-3,274	-1,168	4,983	4,958
2.	Result	275,147	279,316	281,400	284,982
	Goal Deviation	-6,253	-2,084	0	3,582
3.	Result	275,005	278,120	279,184	281,400
	Goal Deviation	-6,395	-3,280	-2,216	0
4.	Result	274,533	278,390	279,943	283,594
	Goal Deviation	-6,867	-3,010	-1,457	2,194
5.	Result	275,352	278,636	282,519	286,458
	Goal Deviation	-6,048	-2,764	1,119	5,058
6.	Result	277,540	280,360	281,290	282,320
	Goal Deviation	-3,860	-1,040	-110	920
7.	(Baseline)				
	Result	275,115	278,978	281,400	284,734
	Goal Deviation	-6,285	-2,422	0	3,334

Table 4

Values of Various End Strengths at End of Year 4

Scenario	Trained E-2	Trained E-3	E-4 to E-9 End Strength	Careerists	Students to "A" School
1. Results	49,139	76,981	286,358	197,300	69,485
Goal Deviation	2,875	-128	4,958	1,120	0
2. Results	46,264	73,491	284,982	196,718	69,201
Goal Deviation	0	-3,618	3,582	538	0
3. Results	46,264	71,346	281,400	196,272	69,258
Goal Deviation	0	-5,763	0	92	0
4. Results	46,264	74,995	283,594	196,707	68,329
Goal Deviation	0	-2,114	2,194	527	0
5. Results	51,876	77,109	286,458	197,455	72,000
Goal Deviation	5,612	0	5,058	1,275	0
6. Results	49,886	70,380	282,320	197,890	82,860
Goal Deviation	3,622	-6,729	920	1,710	10,860
7. (Baseline)					
Results	46,264	74,823	284,734	196,803	68,348
Goal Deviation	0	-2,286	3,334	623	0
Desired Value (all scenarios)	46,264	77,109	281,400	196,180	56,000/ 72,000

FUTURE DEVELOPMENTS

AGAM represents an intermediate step in the genesis of an operational model that is being designed to effectively represent the complex system under investigation, while being computationally efficient. The recruit input optimization (RIO) model, a predecessor of AGAM, is not formulated to represent the force in terms of structured billets and trained strength.[3] Although AGAM is useful in exploring the turbulent force behavior of the lower pay grades and TIS cells, it cannot be linked into more comprehensive systems due to its large size. Therefore, AGAM is being restructured to reduce the number of time intervals utilized by the model. Instead of quarterly time periods, the redesigned model--called the Optimal Accession Requirements Model (OAR)--will use annual time periods.[4] The differences in formulation, size, and solution times of

[3]Yen, Y.-S. Recruit Input Optimization (RIO) Model: Formulation and development. (NPRDC Tech. Rep. 80-12) San Diego: Navy Personnel Research and Development Center, February 1980. (AD-A080 653)

[4]Whisman, A. W. Optimal Accession Requirements (OAR) Model(NPRDC Tech. Rep.) San Diego: Navy Personnel Research and Development Center (in press).

these three models are highlighted in Table 5. Although the OAR model will lack the detailed quarterly output of the other models, it is sufficiently small to guarantee extremely rapid turnaround, allowing it to be used in conjunction with other personnel forecasting models to form a more comprehensive personnel planning system. For example, OAR is being embedded in a larger system in which flow rates are determined by a personnel inventory projection model instead of using historical data directly. In this way, programs and policy can be input to the projection model, thus altering the historical estimates of flow behavior. OAR then can determine an optimal accession schedule, given a set of goals (and penalties), as well as a set of flow rates that reflect management intentions.

Table 5

Characteristics of Accession Planning Models

Characteristics	RIO	AGAM	OAR
Equations (for 5-year model)	4200	4400	390
Strength Goals (by pay grade)	Total	Total Structured Trained	Total Structured Trained
Intervals	Quarter	Quarter	Year
Constraint on Recruit Supply	Upper Bound	Upper and Lower Bounds	Penalty Function
CPU Time (seconds)	650-1000	650-1000	12-27

APPENDIX

FLOW RATES TO VARIOUS PAY GRADES (PGs)

Table A-1

Flow Rates to Pay Grade E-1

LOS	PG From E-1	E-2	E-3	E-4	E-5/9	Gains
<1	0.0	0.0	0.0	0.0	0.0	0.6366
1	0.7660	0.0009	0.0006	0.0	0.0	0.0044
2	0.3404	0.0093	0.0013	0.0	0.0	0.0011
3	0.2857	0.0168	0.0007	0.0	0.0	0.0002
4	0.5230	0.0173	0.0012	0.0	0.0	0.0
5	0.5254	0.0305	0.0004	0.0	0.0	0.0001
6	0.5221	0.0305	0.0013	0.0006	0.0	0.0
7	0.4794	0.0330	0.0016	0.0	0.0	0.0
8	0.5522	0.0274	0.0013	0.0	0.0	0.0001
9	0.4711	0.0428	0.0018	0.0	0.0	0.0
10	0.5073	0.0294	0.0044	0.0002	0.0	0.0
11	0.5165	0.0434	0.0036	0.0006	0.0	0.0
12	0.5000	0.0335	0.0006	0.0	0.0	0.0001
13	0.4696	0.0575	0.0008	0.0010	0.0	0.0
14	0.5095	0.0268	0.0013	0.0	0.0	0.0
15	0.5845	0.0510	0.0031	0.0	0.0	0.0
16	0.3958	0.0096	0.0019	0.0006	0.0	0.0002
17	0.5417	0.0	0.0135	0.0	0.0	0.0
18	0.5000	0.0	0.0089	0.0014	0.0	0.0
19	0.3750	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0012	0.0	0.0
21	0.2500	0.0	0.0	0.0	0.0	0.0
22	0.5000	0.0	0.0	0.0051	0.0	0.0
23	0.3750	0.0	0.0	0.0	0.0	0.0
24	0.2500	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.2500	0.0	0.0	0.0	0.0	0.0
27	0.2500	0.0	0.0	0.0092	0.0	0.0001
28	0.6250	0.0	0.0	0.0	0.0	0.0
29	0.2500	0.0	0.0	0.0	0.0	0.0
30	0.2500	0.0	0.0	0.0	0.0	0.0
31	0.2500	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.0	0.0	0.0
36	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.0	0.0
38	0.0	0.0	0.0	0.0	0.0	0.0
39	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0001
>40	0.4167	0.0	0.0	0.0044	0.0000	0.6430

Table A-2

Flow Rates to Pay Grade E-2

	PG From					
LOS	E-1	E-2	E-3	E-4	E-5/9	Gains
<1	0.0	0.0	0.0	0.0	0.0	0.0809
1	0.0862	0.9076	0.0018	0.0	0.0	0.0022
2	0.5998	0.8809	0.0094	0.0	0.0	0.0024
3	0.5942	0.8845	0.0078	0.0	0.0	0.0004
4	0.2666	0.6265	0.0122	0.0	0.0	0.0005
5	0.2139	0.5493	0.0094	0.0	0.0	0.0002
6	0.1883	0.6175	0.0124	0.0015	0.0	0.0
7	0.2232	0.6307	0.0089	0.0008	0.0	0.0003
8	0.1642	0.5811	0.0138	0.0009	0.0	0.0002
9	0.1198	0.5469	0.0172	0.0007	0.0	0.0
10	0.1526	0.5947	0.0143	0.0019	0.0	0.0
11	0.2088	0.6675	0.0185	0.0007	0.0	0.0002
12	0.1041	0.4283	0.0117	0.0006	0.0	0.0002
13	0.1857	0.6045	0.0226	0.0	0.0	0.0001
14	0.2024	0.6273	0.0140	0.0003	0.0	0.0001
15	0.1571	0.6667	0.0235	0.0008	0.0	0.0001
16	0.0	0.1554	0.0052	0.0005	0.0	0.0
17	0.0	0.7125	0.0149	0.0013	0.0	0.0
18	0.0	0.9375	0.0152	0.0	0.0	0.0
19	0.0	0.6417	0.0135	0.0029	0.0	0.0
20	0.0	0.5750	0.0	0.0	0.0	0.0
21	0.0	0.6667	0.0139	0.0047	0.0	0.0
22	0.0	0.1667	0.0139	0.0	0.0	0.0
23	0.0	0.7500	0.0114	0.0	0.0	0.0
24	0.0	0.7500	0.0470	0.0	0.0	0.0
25	0.0	0.8750	0.0	0.0	0.0	0.0
26	0.0	0.3750	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0500	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.2500	0.0625	0.0	0.0	0.0
32	0.0	0.5000	0.0	0.0	0.0	0.0
33	0.0	0.2500	0.0	0.0	0.0	0.0
34	0.0	0.5000	0.0	0.0	0.0	0.0
35	0.0	0.2500	0.0	0.0	0.0	0.0
36	0.0	0.2500	0.0	0.0	0.0	0.0
37	0.0	0.2500	0.0	0.0	0.0	0.0
38	0.0	0.5000	0.0	0.0	0.0	0.0
39	0.0	0.2500	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0
>40	0.0	0.0	0.0	0.0	0.0	0.0878

Table A-3

Flow Rates to Pay Grade E-3

	PG From					
LOS	E-1	E-2	E-3	E-4	E-5/9	Gains
<1	0.0	0.0	0.0	0.0	0.0	0.1563
1	0.0041	0.0132	0.8899	0.0	0.0	0.0011
2	0.0126	0.0719	0.6579	0.0059	0.0	0.0008
3	0.0116	0.0645	0.6686	0.0103	0.0	0.0007
4	0.0241	0.3182	0.8535	0.0112	0.0	0.0003
5	0.0353	0.3667	0.9425	0.0121	0.0	0.0005
6	0.0193	0.2899	0.9347	0.0088	0.0	0.0008
7	0.0169	0.2626	0.8650	0.0117	0.0	0.0020
8	0.0215	0.2397	0.7396	0.0080	0.0	0.0050
9	0.0246	0.2370	0.6266	0.0065	0.0	0.0013
10	0.0386	0.2166	0.6565	0.0089	0.0	0.0005
11	0.0156	0.1674	0.6912	0.0138	0.0	0.0024
12	0.0208	0.1779	0.6013	0.0099	0.0	0.0071
13	0.0333	0.1884	0.7420	0.0125	0.0	0.0011
14	0.0	0.1655	0.7404	0.0097	0.0007	0.0010
15	0.0	0.1049	0.7172	0.0095	0.0008	0.0029
16	0.0	0.0096	0.3481	0.0062	0.0	0.0048
17	0.0	0.1625	0.7127	0.0080	0.0015	0.0005
18	0.0	0.0625	0.8018	0.0110	0.0	0.0004
19	0.0	0.2583	0.6929	0.0111	0.0008	0.0010
20	0.0	0.1250	0.7365	0.0143	0.0	0.0007
21	0.0	0.0	0.7296	0.0099	0.0	0.0002
22	0.0	0.0	0.6878	0.0115	0.0005	0.0004
23	0.0	0.0	0.7649	0.0039	0.0	0.0002
24	0.0	0.0	0.5878	0.0159	0.0005	0.0003
25	0.0	0.1250	0.7914	0.0036	0.0	0.0002
26	0.0	0.0	0.7194	0.0043	0.0	0.0002
27	0.0	0.0	0.7015	0.0	0.0008	0.0001
28	0.0	0.0	0.5375	0.0	0.0	0.0004
29	0.0	0.0	0.6286	0.0	0.0	0.0
30	0.0	0.0	0.6375	0.0096	0.0	0.0001
31	0.0	0.0	0.3333	0.0	0.0	0.0005
32	0.0	0.0	0.7708	0.0	0.0	0.0002
33	0.0	0.2500	0.3958	0.0071	0.0008	0.0001
34	0.0	0.0	0.7500	0.0100	0.0	0.0002
35	0.0	0.0	0.2500	0.0227	0.0019	0.0004
36	0.0	0.0	0.7143	0.0	0.0	0.0
37	0.0	0.0	0.7083	0.0	0.0	0.0001
38	0.0	0.0	0.5000	0.0	0.0	0.0
39	0.0	0.0	0.6250	0.0	0.0011	0.0001
40	0.0	0.0	0.4375	0.0	0.0	0.0008
>40	0.0	0.0	0.7920	0.0039	0.0000	0.1957

Table A-4

Flow Rates to Pay Grade E-4

LOS	PG From E-1	E-2	E-3	E-4	E-5/9	Gains
<1	0.0	0.0	0.0	0.0	0.0	0.0018
1	0.0010	0.0026	0.0499	1.0000	0.0	0.0003
2	0.0088	0.0101	0.3089	0.9584	0.0	0.0001
3	0.0126	0.0046	0.2971	0.9713	0.0	0.0
4	0.0	0.0005	0.0928	0.9632	0.0	0.0001
5	0.0042	0.0004	0.0334	0.9544	0.0	0.0
6	0.0	0.0015	0.0341	0.9375	0.0	0.0001
7	0.0	0.0	0.1016	0.9069	0.0	0.0
8	0.0	0.0045	0.1913	0.8596	0.0	0.0008
9	0.0054	0.0076	0.2565	0.8282	0.0023	0.0001
10	0.0078	0.0162	0.2511	0.8525	0.0072	0.0006
11	0.0	0.0109	0.2338	0.8875	0.0043	0.0005
12	0.0	0.0033	0.1812	0.8231	0.0080	0.0026
13	0.0	0.0	0.1853	0.8284	0.0063	0.0010
14	0.0	0.0151	0.2039	0.8237	0.0061	0.0004
15	0.0	0.0078	0.1611	0.7653	0.0037	0.0020
16	0.0	0.0114	0.1074	0.4170	0.0023	0.0049
17	0.0833	0.0	0.1760	0.7980	0.0032	0.0010
18	0.1250	0.0	0.1361	0.8341	0.0047	0.0006
19	0.0	0.0	0.2322	0.8083	0.0036	0.0003
20	0.0	0.0	0.1895	0.7817	0.0053	0.0003
21	0.0	0.0	0.1761	0.7877	0.0018	0.0
22	0.0	0.0833	0.2680	0.7778	0.0047	0.0001
23	0.0	0.0	0.1349	0.7825	0.0034	0.0005
24	0.0	0.0	0.2326	0.6933	0.0059	0.0005
25	0.0	0.0	0.1257	0.8003	0.0013	0.0003
26	0.0	0.0	0.1909	0.7497	0.0006	0.0
27	0.0	0.0	0.2152	0.7512	0.0036	0.0
28	0.0	0.0	0.3625	0.8154	0.0021	0.0002
29	0.0	0.0	0.0357	0.8408	0.0007	0.0001
30	0.0	0.0	0.0	0.7579	0.0016	0.0001
31	0.0	0.0	0.1875	0.7750	0.0016	0.0003
32	0.0	0.0	0.1666	0.7870	0.0008	0.0001
33	0.0	0.0	0.2292	0.7830	0.0008	0.0001
34	0.0	0.0	0.0	0.6687	0.0017	0.0001
35	0.0	0.2500	0.3750	0.8021	0.0052	0.0
36	0.0	0.0	0.0	0.8728	0.0008	0.0
37	0.0	0.0	0.0417	0.7704	0.0	0.0
38	0.0	0.0	0.2500	0.8715	0.0021	0.0
39	0.0	0.0	0.1250	0.6788	0.0013	0.0
40	0.0	0.0	0.1667	0.7470	0.0014	0.0005
>40	0.0	0.0	0.1144	0.7672	0.0003	0.0202

Table A-5

Flow Rates to Pay Grade E-5/9

LOS	PG From E-1	E-2	E-3	E-4	E-5	Gains
<1	0.0	0.0	0.0	0.0	0.0	0.0005
1	0.0	0.0	0.0	0.0	0.7500	0.0002
2	0.0	0.0	0.0	0.0	0.6250	0.0001
3	0.0	0.0	0.0010	0.0	1.0000	0.0
4	0.0	0.0	0.0	0.0019	0.9375	0.0
5	0.0	0.0	0.0	0.0123	0.9583	0.0
6	0.0	0.0	0.0003	0.0364	0.9405	0.0
7	0.0	0.0	0.0	0.0671	0.9911	0.0
8	0.0	0.0	0.0	0.1113	0.9876	0.0
9	0.0	0.0	0.0004	0.1125	0.9820	0.0002
10	0.0	0.0	0.0003	0.1011	0.9736	0.0002
11	0.0	0.0	0.0	0.0651	0.9824	0.0001
12	0.0	0.0	0.0	0.0806	0.9808	0.0001
13	0.0	0.0	0.0018	0.1338	0.9847	0.0002
14	0.0	0.0	0.0	0.1519	0.9910	0.0002
15	0.0	0.0	0.0022	0.1378	0.9124	0.0009
16	0.0500	0.0	0.0	0.0863	0.6702	0.0030
17	0.0	0.0	0.0	0.1317	0.9545	0.0006
18	0.1250	0.0	0.0	0.1287	0.9731	0.0007
19	0.0	0.0	0.0	0.1427	0.9768	0.0002
20	0.0	0.0	0.0064	0.1499	0.9752	0.0002
21	0.0	0.0	0.0076	0.1719	0.9887	0.0001
22	0.0	0.0	0.0	0.1786	0.9811	0.0002
23	0.0	0.0	0.0178	0.1435	0.9462	0.0004
24	0.0	0.0	0.0	0.1428	0.8191	0.0009
25	0.0	0.0	0.0147	0.1617	0.9797	0.0003
26	0.0	0.0	0.0	0.2145	0.9898	0.0001
27	0.0	0.0	0.0	0.2034	0.9812	0.0005
28	0.0	0.0	0.0	0.1671	0.9601	0.0007
29	0.2500	0.0	0.0	0.1433	0.9831	0.0005
30	0.0	0.0	0.0	0.1814	0.9857	0.0003
31	0.0	0.0	0.0	0.1768	0.9658	0.0006
32	0.0	0.0	0.0	0.1426	0.9492	0.0004
33	0.0	0.0	0.0	0.1937	0.9579	0.0002
34	0.0	0.0	0.0	0.2798	0.9703	0.0005
35	0.0	0.0	0.0	0.1392	0.9571	0.0003
36	0.0	0.0	0.0	0.0869	0.9615	0.0003
37	0.0	0.0	0.0	0.1629	0.9766	0.0002
38	0.0	0.0	0.0	0.1011	0.9754	0.0007
39	0.0	0.0	0.0	0.2745	0.9535	0.0007
40	0.0	0.0	0.0	0.2321	0.9670	0.0070
>40	0.0833	0.0	0.0	0.2002	0.9660	0.0220

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